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Bioresource Technology 99 (2008) 1861–1868

BIORESOURCE TECHNOLOGY

The effects of heat treatment on some technological properties of Scots pine (*Pinus sylvestris* L.) wood

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Received 14 February 2007; received in revised form 15 March 2007; accepted 19 March 2007
Available online 7 May 2007

Abstract

Heat treatment is often applied to wood species to improve their dimensional stability. This study examined the effect of heat treatment on certain mechanical properties of Scots pine (*Pinus sylvestris* L.), which has industrially high usage potential and large plantations in Turkey. Wood specimens obtained from Bolu, Turkey, were subjected to heat treatment under atmospheric pressure at varying temperatures (120, 150 and 180 °C) for varying durations (2, 6 and 10 h). The test results of heat-treated Scots pine and control samples showed that technological properties including compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain suffered with heat treatment, and increase in temperature and duration further diminished technological strength values of the wood specimens.

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Keywords: Thermal treatment; Scots pine wood; Mechanical properties; *Pinus sylvestris* L.

1. Introduction

Scots pine has superior technological properties and high usage potential. It is an important tree species in the forest products industry of Turkey, covering over one million ha, making up 5% of the total Turkish forestlands (Anonymous, 2001).

Heat treatment is one of the processes used to modify the properties of wood (Mazela et al., 2004). Heat treatment, as a wood modification method, serves to improve the natural quality properties of the wood, such as dimensional stability and resistance to bio-corrosion and equip the wood material with new properties.

The heat treatment process involves exposing wood to elevated temperatures ranging from 160 to 260 °C (Militz, 2002). The temperature and duration for heat treatment generally vary from 180 to 280 °C and 15 min to 24 h depending on the process, wood species, sample size, moisture content of the sample and the desired mechanical properties, resistance to biological attack, and dimensional stability of the final product (Militz, 2002; Kamdem et al., 2002; Sanderman and Augustin, 1963).

Reports from various studies indicate that the effect of high-temperature heating (particularly above 175 °C) on strength and brittleness of wood varies depending on the chemical and anatomical nature of the wood and the methods of heating (Hillis, 1984). In other words, the extent of the change in timber properties during heat treatment is determined by the method of thermal modification, the wood species and its characteristic properties, the initial moisture content of the wood, the surrounding atmosphere, and the treatment temperature and time. It is reported that temperature has a stronger effect on timber properties than the amount of time the timber is exposed to heat (Mitchell, 1988). Treating wood at lower temperatures for longer time periods does not produce the desired properties. Temperatures over 150 °C alter the physical and chemical properties of wood gradually (Syrjanen and Oy,

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doi:10.1016/j.biortech.2007.03.038

2001; Mitchell, 1988). The higher the treatment temperature the better the wood's biological durability. However, at temperatures over 150 °C the strength properties start to weaken. The wood becomes more brittle, and bending and tension strength decrease by 10–30%. Therefore, the use of heat-treated wood in load-bearing constructions is restricted (Jamsa and Viitaniemi, 2001).

Heat treatment reduces certain mechanical properties, but the dimensional stability and the biological durability of wood increases through heat treatment. In addition, heat treatment results in favorable changes in the physical properties of the wood, such as reduced shrinkage and swelling, low equilibrium moisture content, enhanced weather resistance, a decorative dark color, and better decay resistance (Yildiz, 2002). Therefore, heat-treated wood is an eco-friendly alternative to impregnated wood materials, and heat-treated wood can be used for garden, kitchen and sauna furniture, cladding on wooden buildings, bathroom cabinets, floor material, musical instruments, ceilings, inner and outer bricks, doors and window joinery, and a variety of other outdoor and indoor wood applications (Syrjanen and Oy, 2001).

Industrial-scale heat treatment process was developed at the Technical Research Center of Finland in the early 1990's. The total production capacity of heat-treated wood in 2002 is estimated approximately to be 265 000 m^3 (Syrjanen and Oy, 2001; Rapp, 2001). Recent efforts on thermal treatment of wood have led to the development of several treatment processes, and materials produced through thermal treatments have been introduced to the European market. Some of the products developed by thermal treatment include Thermowood (Stellac) in Finland (Viitaniemi et al., 1994), Torrefaction (Perdure) in France (Weiland and Guyonnet 1997) and PLATO-Wood in the Netherlands (Militz, 2002).

Research on the effects of heat treatment on the technological properties of Turkish native trees is rather limited. This study aims at examining the effects of heat treatment on technological properties of Scots pine (*Pinus sylvestris* L.) wood, which has not been done before. Scots Pine is one of the most common wood species naturally grown and intensively used in the forest product industry in Turkey. Improving the characteristics of Scots pine through heat treatment would offer the timber product industry many interesting opportunities.

2. Methods

Scots pine logs (min. diameter 40–50 cm) were obtained from Aladağ-Bolu, Turkey. Lumber from the logs was prepared in the sawmill of Forestry Faculty, Istanbul University, Turkey [TS 4176]. Scots pine lumber was planed with a knife angle of 45° and then small clear specimens were cut for compression strength parallel to grain (2 × 2 × 3 cm), bending strength (2 × 2 × 36 cm), modulus of elasticity in bending (2 × 2 × 36 cm), janka-hardness (5 × 5 × 5 cm), impact bending strength (2 × 2 × 30 cm) and tension strength perpendicular to grain (2 × 3 × 7 cm) [TS 2470].

A total of 5 wood samples with a breast diameter ($d_{1.30\ \mathrm{m}}$) of 40–50 cm was taken from Bolu Forest Enterprises. The forest where the samples were taken from had an altitude of 1540 m and a slope of 38%.

The number of specimens taken from each log was equal. Specimens were divided into 9 treatment groups and for each group, a total of 30 test and 30 control samples were used. Heat treatment was applied to the samples at three controlled (±1 °C) temperatures (120, 150, 180 °C) for three durations (2–6–10 h) under atmospheric pressure. After heat treatment, treated and untreated samples were conditioned to 12% moisture contents (MC) in a conditioning room at 20 °C ± 2 °C and with 65% (±5) relative humidity (RH) according to TS 642. Prior to the test, the dimensions of the samples were measured to the nearest 0.001 mm and their weights to the nearest 0.01 g. Tests of the compression strength parallel to grain (TS 2595) [(TS 2595, 1976)], bending strength (TS 2474), modulus of elasticity in bending (TS 2478), janka-hardness (TS 2479), impact bending strength (TS 2477) and tension strength perpendicular to grain (TS 2476) were carried out and the values were determined for treated and untreated (control) samples.

Upon conducting the experiments the moisture contents (the moisture content deviation from 12 percent) of the specimens were measured according to TS 2471 and strength values were corrected (transformed to 12% moisture content) using the following strength conversion equation:

$$\delta_{12} = \delta_{\mathrm{m}}^{*}[1 + \alpha(M_2 - 12)]$$

where δ_{12} is the strength at 12% moisture content (N/mm^2), δ_{m} is the strength at moisture content deviated from 12 percent (N/mm^2), α is the constant value showing relationship between strength and moisture content and M_2 is the moisture content during the experiment (%).

The data were analyzed using analysis of variance (ANOVA), and significant differences between control and treated samples were determined by Duncan's Multiple Range Test.

3. Results and Discussion

Table 1 shows the changes in the compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain at varying treatment temperature and durations. The values indicate that heat treatment diminished the technological properties of Scots pine. ANOVA and Duncan's Multiple Range Tests show that all differences were significant (Table 1). Furthermore, as (Table 2) shows an increase in time and duration resulted in greater decreases in treated samples compared to the control samples. As a result, the changes were the largest at 180 °C for 10 h. Table 2 shows the levels of

Table 1
Relationship between heat treatment based on treatment times and compression strength, bending strength, modulus of elasticity in bending, janka-hardness, impact bending and tension strength perpendicular to grain

Heat treatment (°C)	Times (h)	Unit	Compression strength (N/mm^2)	Bending strength (N/mm^2)	Modulus of elasticity in bending (N/mm^2)	Janka-hardness			Impact bending (J/cm^2)	Tension strength perpendicular to grain (N/mm^2)
						Cross-section	Radial	Tangential		
None		Avg.	**59.713 A**	**138.026 A**	**1472.776 A**	**66.641 A**	**30.478A**	**32.078 A**	**7.208 A**	**3.433 A**
		±s	7.681	33.300	1059.887	12.324	6.263	6.312	1.901	0.498
120	2	Avg.	**57.998 ABC**	**136.873 AB**	**1363.817 A**	**55.578 BCDEFGH**	**30.19 AB**	**30.797 AB**	**6.980 A**	**3.032 B**
		±s	6.813	25.529	284.762	11.122	5.504	4.453	1.703	0.373
	6	Avg.	**56.655 ABCD**	**134.513 AB**	**1302.986 ABCD**	**54.751 CDEFGHI**	**28.489 ABC**	**30.507 AB**	**6.635 AB**	**2.672 CDE**
		±s	8.323	33.416	336.146	7.710	6.341	7.147	2.334	0.605
	10	Avg.	**55.998 ABCDE**	**124.793AB**	**1267.596 ABCDE**	**54.597 DEFGHI**	**27.542 ABCD**	**28.110 BCDE**	**6.475 AB**	**2.655 DE**
		±s	7.686	21.103	464.324	9.447	4.959	5.889	2.113	0.428
150	2	Avg.	**54.924 BCDE**	**122.723 ABC**	**1194.534 BCDEFG**	**53.844 EFGHI**	**27.232 BCD**	**27.367 CDE**	**6.221 ABC**	**2.448 EF**
		±s	8.650	32.688	246.0673	6.274	6.390	5.167	2.237	0.563
	6	Avg.	**54.425 CDEF**	**122.133 ABC**	**1111.762 CDEFG**	**52.755 FGHI**	**26.270 CD**	**26.204 DE**	**5.749 BCD**	**2.3172 FGHI**
		±s	9.615	30.544	242.27839	10.266	4.166	5.450	1.752	0.692
	10	Avg.	**54.026 DEF**	**120.747 ABC**	**1060.498 DEFG**	**52.308 GHI**	**25.121 DEFG**	**26.001 E**	**5.404 CDE**	**2.124 GHIJ**
		±s	6.725	33.190	232.2352	10.029	5.439	5.599	2.318	0.467
180	2	Avg.	**51.916 EF**	**117.527 BC**	**1040.49 EFG**	**51.492 HI**	**23.274 EFG**	**21.999 FGH**	**4.819 DEF**	**2.121 HIJ**
		±s	10.098	41.045	17.091	6.918	6.774	5.310	1.659	0.665
	6	Avg.	**50.293 F**	**106.268 C**	**1001.483 FG**	**49.609 I**	**22.227 FG**	**21.632 GH**	**4.667 EF**	**2.051 IJ**
		±s	7.502	35.362	244.169	9.251	4.799	4.904	1.414	0.396
	10	Avg.	**44.541 G**	**92.914 D**	**999.637 G**	**39.320 J**	**22.121 G**	**19.579 H**	**4.149F**	**1.846 J**
		±s	3.918	6.734	113.5461	5.269	3.759	6.132	0.850	0.480

Avg: average; ±S: standard deviation; *N*: number of samples used in each test (30); $^*p < 0.05$. Homogeneity groups: same letters in each columns indicate that there is no statistical difference between the samples according to the Duncan's multiply range test.

Table 2
Decreases in the values of measured parameters, as a result of temperature and times in heat treatment, in relation to control

Heat treatment (°C)	Times (h)	Compression strength (%)	Bending strength (%)	Modulus of elasticity in bending (%)	Janka-hardness			Impact bending strength (%)	Tension strength perpendicular to grain (%)
					Cross-section	Radial	Tangential		
120	2	2.87	0.83	7.39	16.60	0.94	3.99	3.16	11.68
	6	5.12	2.54	11.52	17.84	6.52	4.89	7.94	22.16
	10	6.22	9.58	13.93	18.07	9.63	12.36	10.16	22.66
150	2	8.02	11.08	18.89	19.20	10.65	14.68	13.69	28.69
	6	8.85	11.51	24.51	20.83	13.80	18.31	20.24	32.50
	10	9.52	12.51	27.99	21.50	17.57	18.94	25.02	38.12
180	2	13.05	14.85	29.35	22.73	23.63	31.42	33.14	38.21
	6	15.77	23.01	32.00	25.55	27.07	32.56	35.25	40.25
	10	25.40	32.68	32.12	40.99	27.41	38.96	42.43	46.22

decreases in sample values with increased thermal treatments. As can be seen, a lesser effect of heat treatment was observed when the samples were treated at 120 °C for 2 h (see, Figs. 1–4).

The lowest compression strength value obtained was at 180 °C for 10 h (44.541 N/mm^2), total loss compared to the control was calculated to be 25.40%. Similarly, the lowest bending strength values were also obtained for samples treated at 180 °C for 10 h (92.914 N/mm^2). The bending strength loss, compared to the control was 32.68%. The lowest modulus of elasticity in bending values was again obtained for samples treated at 180 °C for 10 h (999.657 N/mm^2). The decrease in modulus of elasticity in bending was 32.12%. The lowest impact bending strength values were for samples treated at 180 °C for 10 h (4.149 J/cm^2). The loss of impact bending strength when compared to controls was 42.43%. The lowest tensile strengths perpendicular to grain values were at 180 °C for 10 h (1.846 N/mm^2). The loss of tensile strength perpendicular to grain was 46.22%. Maximum hardness loss was obtained for samples treated at 180 °C for 10 h; cross-section 40.99%, radial 27.41% and tangential 38.96%.

In general the results of this study on the effect of heat treatment on Scots pine are compatible with the findings in the literature on the effect of heat treatment on different tree species. Ünsal Ö et al. (2003) reported that in Turkish river red gum (*Eucalyptus camaldulensis* Dehn.) wood samples the largest hardness loss was at 180 °C and 10 h. The loss was 23.91% cross-sectionally, 44.20% radially, and

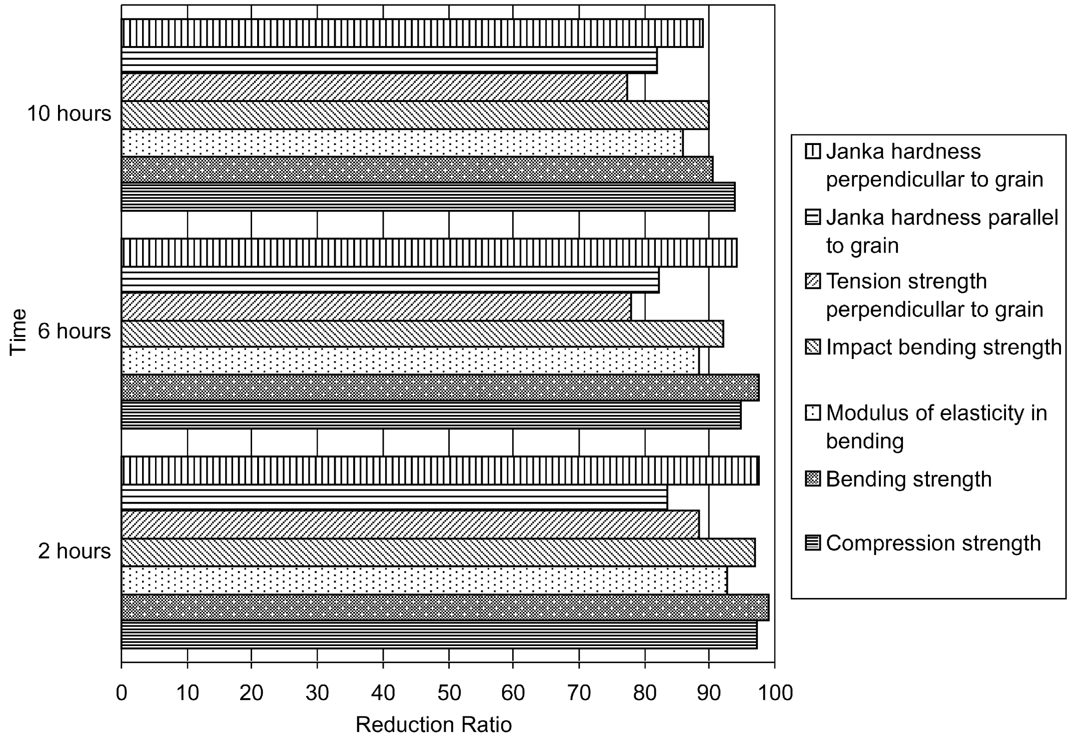

Fig. 1. Reduction ratios based on times at 120 C° heat treatment.

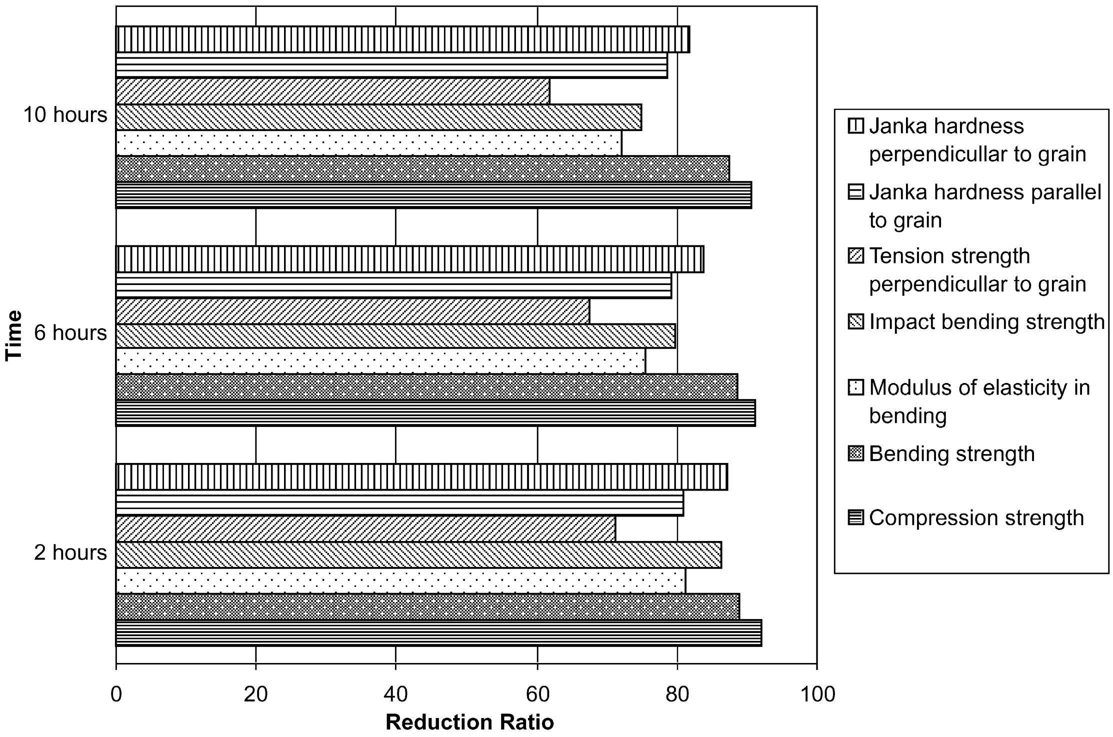

Fig. 2. Reduction ratios based on times at 150 C° heat treatment.

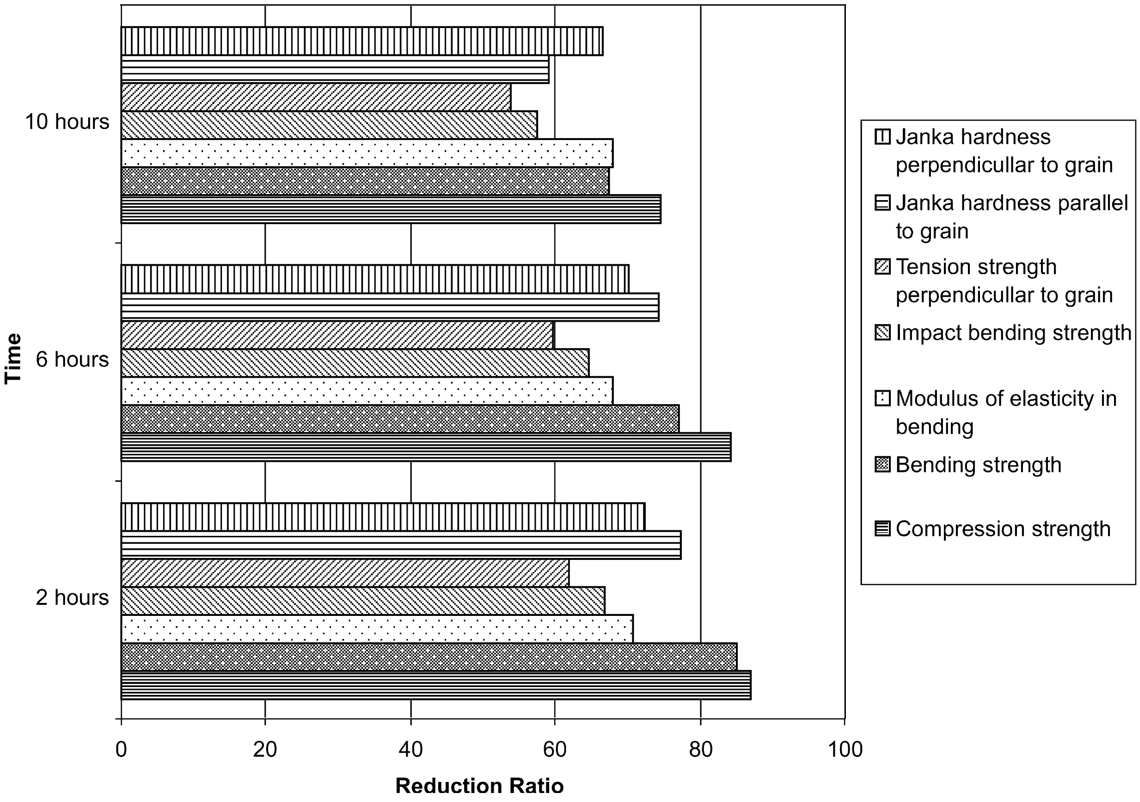

Fig. 3. Reduction ratios based on times at 180 C° heat treatment.

33.57 % tangentially. Unsal and Ayrilmis (2005) also found that the maximum compression strength parallel to grain decrease in Turkish river red gum (*E. camaldulensis* Dehn.) wood samples was 19.0% at 180 °C and 10 h.

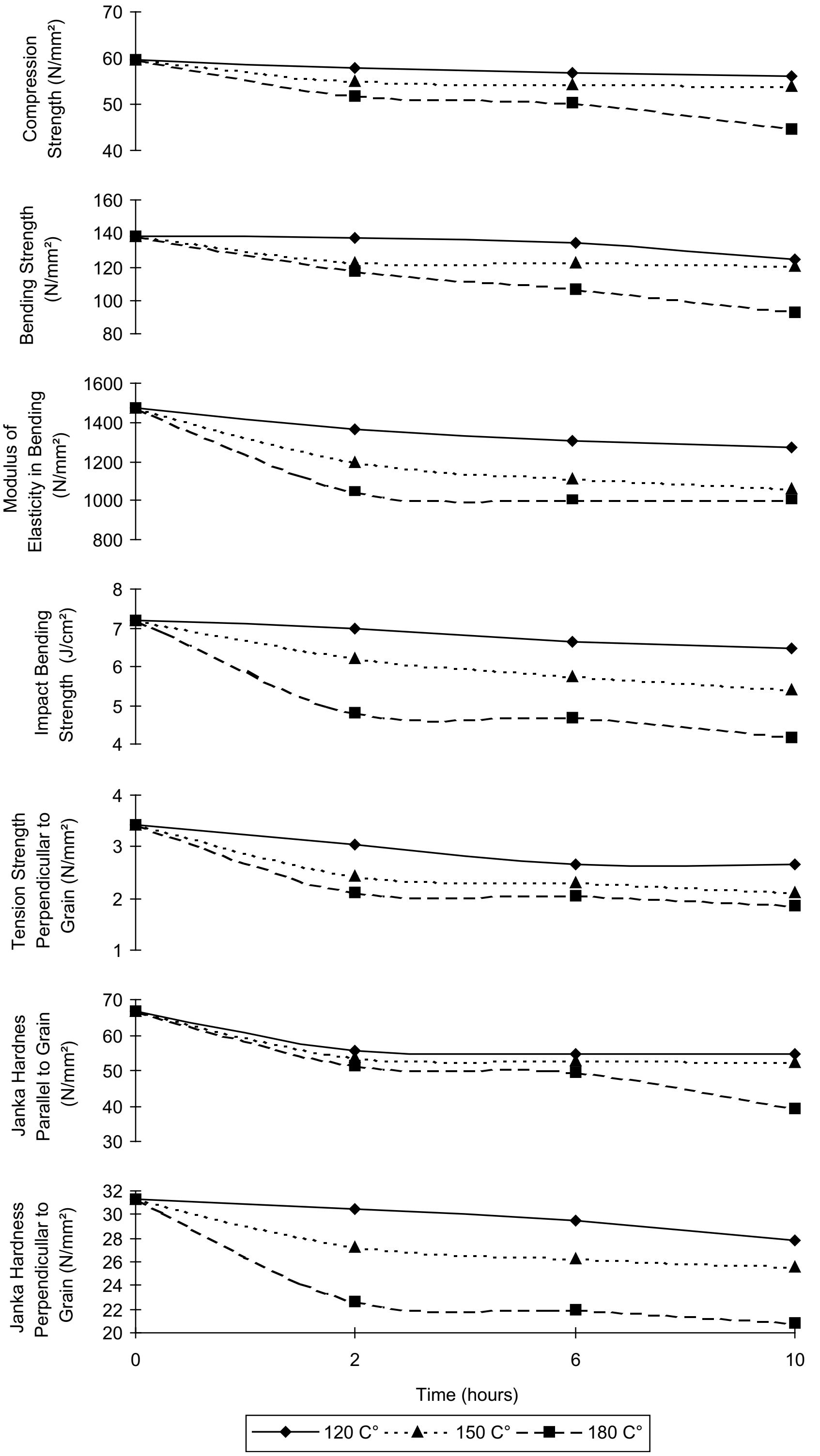

Fig. 4. The effects of heat treatment on strength properties of wood.

A similar study was conducted by Yildiz (2002) with oriental beech and spruce. For oriental beech at 180 °C for 10 h, the decrease in values was as follows: cross-section 25.9%, radial 45.1% and tangential 41.8%. For spruce, cross-section, radial direction and tangential value losses were measured to be 19.7%, 43.0% and 42.5%, respectively. Heat treatment of spruce (*Picea orientalis* L.) and beech (*Fagus orientalis* L.) at 200 °C for 6 h resulted in a 36% decrease in compression strength. On the other hand, a slight increase in compression strength was observed at 130 °C for 6 h. In the same study, it was noted that compression strength was affected less by temperature increase compared to the other strength properties. The highest decrease in the modulus of elasticity for spruce was found to be 41.5% at 200 °C for 6 h. However, at 130 °C for 10 h a slight increase (8.4%) was observed in the modulus of elasticity. For beech, heat treatment at 200 °C for 10 h resulted in an increase in modulus of elasticity (39%). The lowest bending strengths for beech and spruce were observed when the wood samples were treated at 200 °C for both 6 h and 10 h. The decrease was 63.9% and 63.6% for beech and 63.8% and 72.7% for spruce for 6 h and 10 h treatment time at 200 °C.

In another study on the effect of heat treatment on pine sapwood, it was observed that with (40 in thick) pine wood samples heated at 110, 130, 150 and 180 °C, the compression strength decreased 5% (Schnerder, 1973). Vital et al. (1983) reported a study of compression parallel to grain in *Eucalyptus saligna* wood samples heated at 100–155 °C for 10–160 h and they found that the compression strength values generally deteriorated with increase in temperature or exposure time.

Bending strength (Kubojima et al., 2000) and modulus of elasticity (Rusche, 1973) were reported to decrease up to 30–50% under drastic heat treatment conditions. Also, an average decrease in bending strength as high as 44–50% was also reported (Bekhta and Niemz, 2003). Giebeler (1983) treated wood at 180–200 °C in the presence of moisture and found that these treatments resulted in 20–50% reduction in the resistance to shock, modulus of elasticity (MOE), modulus of rupture (MOR) and compression strengths.

The decreases in the strength properties can be explained by the rate of thermal degradation and losses of substance after heat treatments. The decrease in strength is mainly due to the depolymerization reactions of wood polymers (Kotilainen, 2000; Wikberg and Maunu, 2004).). The primary reason for the strength loss is the degradation of hemicelluloses, which are less resistant to heat than cellulose and lignin. Changes in or loss of hemicelluloses play key roles in the strength properties of wood heated at high-temperatures (Hillis, 1984).

4. Conclusion

In this study on Scots pine (*P. sylvestris* L.) wood, it was found that compression strength parallel to grain, bending strength, modulus of elasticity in bending, janka-hardness, impact bending strength and tension strength perpendicular to grain decrease by heat treatment. Furthermore, the results showed that an increase in time and duration resulted in greater decreases in treated samples compared to the control samples. On the other hand, the smallest decreases were observed in the treatment at 120 °C for 2 h. It should, however, be noted that strength losses can be limited by alternative advanced heat treatment techniques. Through heat treatment various tree species can be utilized using proper heat treatment techniques without any loses in strength values in areas, where woodworking and stability are important. Also, through heat treatment wood species with no commercial value can be used in areas where they had no use previously.

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